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WELDABILITY OF LINE-PIPE STEEL AG

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WELDING SECTION

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WELDABILITY OF LINE PIPE STEEL AG

by

R.D. McDonald and M.W. Letts

ABSTRACT

Weldability tests were performed on sections of seam welded IPSCO pipe. These included manual welds and implant tests using coated high yield cellulosic electrodes. In addition, fracture toughness of the seam weld was assessed by using standard Charpy impact test specimens.

The tests demonstrated good weldability and sound welds were obtained. Low to moderate hydrogen cracking susceptibility was indicated by implant tests and by hardness values recorded in the weld metal and heat-affected zones.

The transition curve, using Charpy impact specimens, showed low values of impact energy of the seam weld metal when compared with the pipe material. The weld metal would not meet the fracture toughness criterion specified in Foothills Engineering Specification P-100, Revision 3.

INTRODUCTION

The evaluation of weldability of Gr. 70 line pipe AG is part of a continuing program wherein chemistry, mechanical properties, and weldability are studied in relation to steel processing, thermal history and section thickness. This report provides data on the weldability of pipe AG for comparison with pipe AB which has previously been tested (1, 2). Both pipe materials were obtained from a Canadian steel manufacturer, pipe AG being the replacement of pipe AB. The pipe AB was not typical of Gr. 70 pipe because it was made for a different purpose. It was semi-killed with silicon and had a sulphur content higher than normal. Elongated silicates and sulphides were present in the microstructures and fracture toughness was lower than required (3).

Pipe AG, made in 1980, was fully deoxidized with aluminum and desulphurized with calcium. The sulphides that remained in the steel were globular. The steel composition is shown in Table 1.

The pipes were produced from coiled strip rather than from plate. Both AB and AG were ingot-cast electric-furnace steel which was coiled into skelp on a "Steckel" mill, and spiral welded into 1067 mm diam. pipe. The weld was at an angle of 70° to the pipe axis. The tandem submerged-arc welding process was used and the pipes were not cold expanded. The dimensions of pipe AG as received were:

length	24.4 m
diameter D	1067 mm
wall thickness	13.72 mm.

PROCEDURES

From the large section of pipe, small sections were removed by flame cutting for weldability tests, (Fig. 1).

Manual Welding Tests

The specimens used in the field welding tests were cut 30.5 cm square and V-grooved at right angles to the pipe axis. They had a 60° angle, a 1.59 mm gap and a 1.59 mm land, Fig. 2. Two specimens were provided to permit welding tests. The procedures used for welding these specimens conformed to

conventional line-pipe, field-welding practices and the parameters are given in Table 2.

The welds were radiographed then cut into sections to permit hardness surveys and visual examination of the weld zones.

Susceptibility of Hydrogen Cracking

Implant tests were carried out on specimens parallel to the pipe axis (perpendicular to a girth weld) and on specimens perpendicular to the seam weld (transverse to the rolling direction). These tests were performed to demonstrate the degree of susceptibility to hydrogen cracking in a heat-affected zone (HAZ). An E7010 HYP cellulose-coated electrode, 4.36 mm in diameter, was used and the tests were performed as previously described (4).

Fracture Toughness at the Seam Weld

Charpy specimens were machined in a direction transverse to the seam weld. Notches located in the weld metal at the centre line were machined in the through-thickness direction. The specimens were tested over a range of temperatures to determine the fracture toughness transition curve of the weld metal.

EXPERIMENTAL RESULTS

Manual Welding Tests (field tests)

These tests were accomplished without any problems using the downhand position. No preheating was required to obtain a sound weld and no cracking occurred in the HAZ. Radiography was used to demonstrate soundness.

Typical hardness values (VHN) relative to weld zones are shown in Fig. 3. A maximum hardness of 245 VHN was obtained on the base metal. The minimum hardness, 181 VHN, was obtained in the fine-grained heat-affected zone (FG HAZ) and in the refined weld metal.

Implant Test

The stress versus time-to-rupture curves, parallel to the pipe axis, are shown in Fig. 4, and perpendicular to the seam weld are shown in Fig. 5. The critical or limiting stress was about 468 MPa for the pipe-axis orientation (Fig. 4), and about 482 MPa for the seam weld orientation (Fig. 6 and

Table 3). Fracture occurred in the coarse-grained heat-affected zone (CG HAZ) close to the fusion line as shown in Figs. 5 and 7.

Fracture Toughness at Seam Welds

The Charpy impact energy versus temperature curve for the seam weld-metal is shown in Fig. 8. The average impact energy of the weld metal was 46 J at -4°C and 22 J at -23°C.

Specification P-100, Revision 3, Foothills Pipelines (Yukon) Ltd., has a minimum requirement of 28 J at the design temperature for welds at 35° or more to the longitudinal axis of the pipe. The angle as measured from the longitudinal axis of pipe AG is 70°.

The transition curve, Fig. 8, shows that a value of 28 J is attained in the weld metal at about -17°C.

The microstructural constituents of the seam weld, with seam-weld hardness values, are shown in Figs. 9 and 10. A view of the microstructure of the seam weld-metal in pipe AB is shown for comparison.

DISCUSSION

Manual or Field Weldability

The results indicate that sound welds can be obtained in this material using room temperature conditions and normal stick-welding practice with E7010 HYP cellulosic electrodes. No cracking or porosity was detected either visually or in radiographs of the weld.

Hardness in the weld zones did not exceed the 350 VHN maximum permitted by P-100, Revision 3. Actual hardness values obtained in the weld metal and HAZ were less than those of the base metal indicating a low susceptibility to hydrogen cracking.

Hydrogen Cracking Susceptibility

A degree of susceptibility to hydrogen cracking occurred in both orientations tested, i.e., parallel to the pipe axis and perpendicular to the seam weld, Figs. 3 to 6. The lowest stresses which caused cracking were within the range 468 to 482 MPa indicating no substantial difference in stress level with orientation.

The greater delay times demonstrated by specimens perpendicular to the seam weld, at the higher loads, could indicate a possible effect on hydrogen mobility.

From implant tests done by Gordine (4) it has been shown that a steel with a high susceptibility to cracking had a HAZ hardness of 422 VHN and a critical stress of 407 MPa, whereas the least susceptible steel had a HAZ hardness of 274 VHN and a critical stress of 600 MPa. Although hardnesses as high as 362 VHN were encountered in implant CGHAZ regions in AG, most values were less than 300 VHN. These values in association with the critical cracking stresses indicate a moderate susceptibility.

Hardness of the seam and the manual weld metals were not in excess of 250 VHN and were generally softer than the base metal indicating that hardness developed during normal welding operations would not be conducive to hydrogen cracking in the weld metal.

Fracture Toughness of Seam Weld-Metal

The impact-energy transition curve does not show excessive scatter and, on average, would meet the standard of 28 J at a temperature of -17°C. This suggests a design temperature limited to -17°C, although P-100, Revision 3 cites design temperatures of -23°C and -4°C for Gr. 70 pipe.

At -23°C and -4°C impact energies of 190 J and 212 J, respectively, were reported for line-pipe steel AG(5). According to P-100, Revision 3, the weld-metal energy cannot be less than 75% of the energy of the base material, i.e. 143 J at -23°C and 159 J at -4°C. Energies in the seam weld-metal of AG or -23°C and -4°C are 22 J and 46 J, respectively, which indicates the toughness of these welds is inadequate.

Comparison of the Charpy impact energies of seam weld-metals in pipe AG, pipe AB and a Z pipe (6), show superior values for pipe AB. Energy values for pipe AG are between those of pipe AB and pipe Z. Visual comparison of the inclusions in the weld metals of pipes AG and AB by optical microscopy (using 100 and 250 magnifications) did not show a distinctive difference between the pipes. However, the acicular ferrite in the microstructure appeared finer in the weld-metal of pipe AB, than in pipe AG (Fig. 10). There also appeared to be less plate or lath type of ferrite in the weld-metal of pipe AB than AG. It has been demonstrated (7, 8) that these microstructural characteristics (of pipe AB) should provide superior low-temperature toughness in the weld metal.

CONCLUSIONS

1. The manual (field) weldability of pipe AG is satisfactory in terms of weld soundness and microstructure when using AWS E7010 HYP electrodes at room temperature.
2. Hydrogen cracking would not be expected in pipe AG under normal welding conditions.
3. The fracture toughness of the seam weld metal, at an angle of 70° to the pipe axis, does not meet the requirements of 75% of the toughness value obtained for the pipe as defined in P-100, Revision 3, Foothills Pipeline.

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2. M.J. Godden and J.T. McGrath, "The Assessment of HAZ Toughness of Line Pipe Steels", CANMET Division Report ERP/PMRL 80-51 (J), Energy, Mines and Resources, Canada, 1980.

3. Foothills Pipelines (Yukon) Ltd., Eng. Spec. P-100, (1978).

4. J. Gordine, "The Weldability of Some Arctic-Canada Line-Pipe Steels", Welding Journal Res. Supp., July 1977.

5. B. Casault, Private Communication.

6. G.T. McGrath, M.J. Godden, J. Gordine and J.D. Boyd, "Fracture Resistance of Pipeline Weldments", Canadian Metallurgical Quarterly, Vol. 19, pp 99-113, 1980. Canadian Institute of Mining and Metallurgy.

7. E. Levine and D.C. Hill. "Structure-Property Relationships in low C. Weld Metal. Metallurgical transactions, Vol. 8 A, 1453, (Sept. 1977).

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able 1. Chemical composition of pipes

ipe		Chemical composition, per cent by weight												
		C	Mn	Si	Al	S	P	Nb	Ce	La	Mo	Cr	Ni	Cu	V
B	PMRL (Av)	0.03	1.73	<0.005	<0.002	0.010	0.010	0.046	-	-	0.21	0.04	0.11	0.20	-
G	PMRL (Av)	0.07	1.63	0.13	0.02	0.008	0.012	0.070	<0.005	0.005	0.20	0.09	0.20	-	0.01

Table 2. Welding consumables and process parameters for manual field weld tests (30.5 cm x 30. 5 cm test coupons).

Steel	Pipe AG Gr X70
Process	Shielded metal-arc welding (SMA)
Electrode	7010 Gr HYP, 4 mm passes 1 to 4
Cellulose-coated	7010 Gr HYP, 4.76 mm passes 5 to 7
Preheat	None
Current (A)	145-165 (4 mm electrode)
	160-180 (4.76 mm electrode)
Characterization	Direct current reverse polarity
Land	1.59 mm ; Gap 1.59 mm
Speed	

Table 3. Summary of results of implant tests

Orientation	Lower critical stress MPa	(ksi)	Maximum HAZ Hardness	VHN*
⊥ Seam weld	482	(70)	362	CGHAZ
" To pipe axis	468	(68)	357	CGHAZ

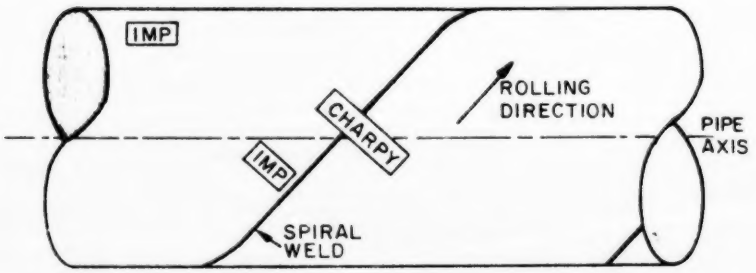


Fig. 1. Schamatic diagram or seam weld in sprial welded line pipe showing location of specimens. (neg 5907)

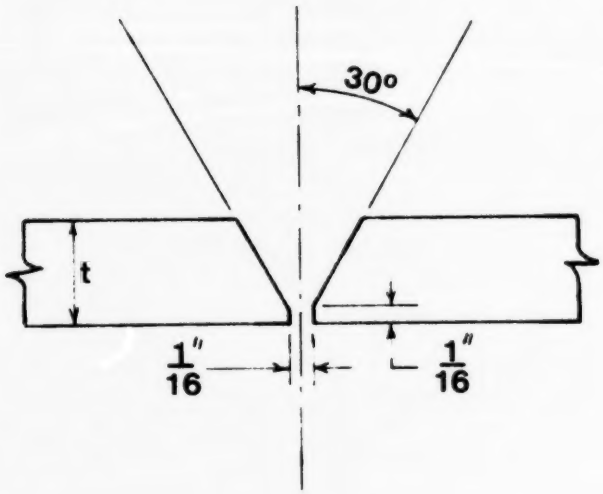


Fig. 2. Joint preparation used for manual welding. (neg 5716)

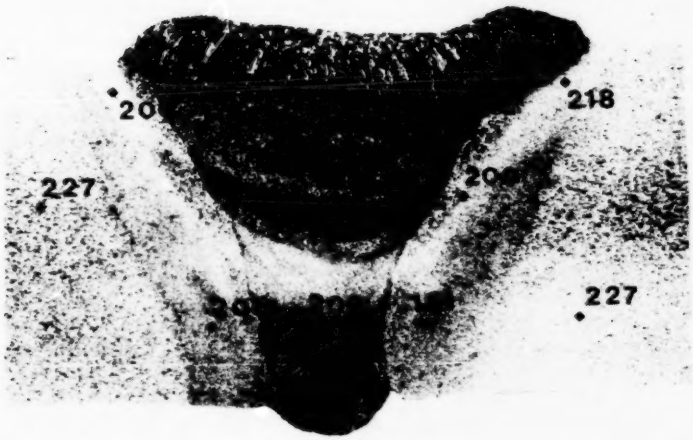


Fig. 3. Weld zones and typical hardness, VHN, for manual welds. X2.5. (neg 5905)

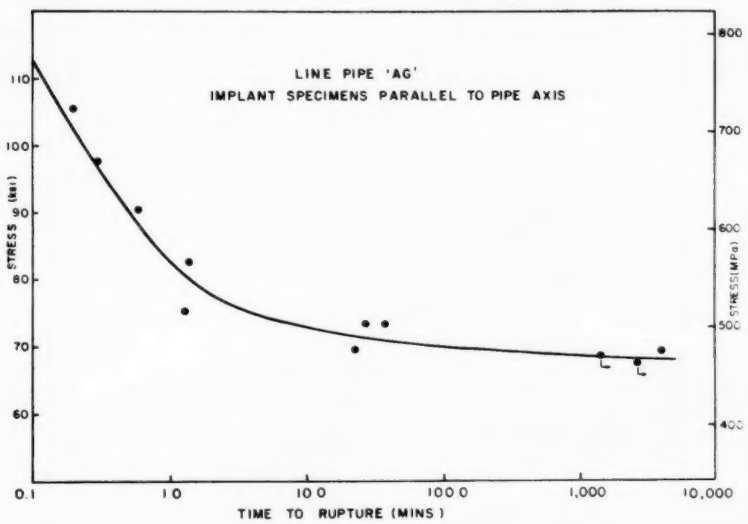


Fig. 4. Implant test results for specimens oriented parallel to the pipe axis. (neg 5906)

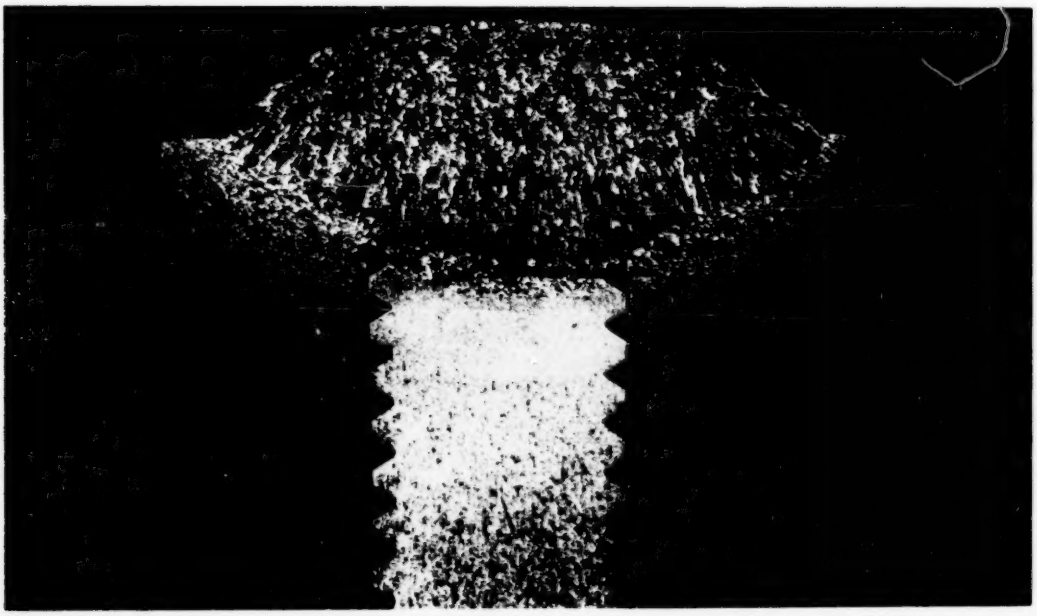


Fig. 5. Cross section through fractures implant specimens oriented parallel to the pipe axis. X5. (neg 5911)

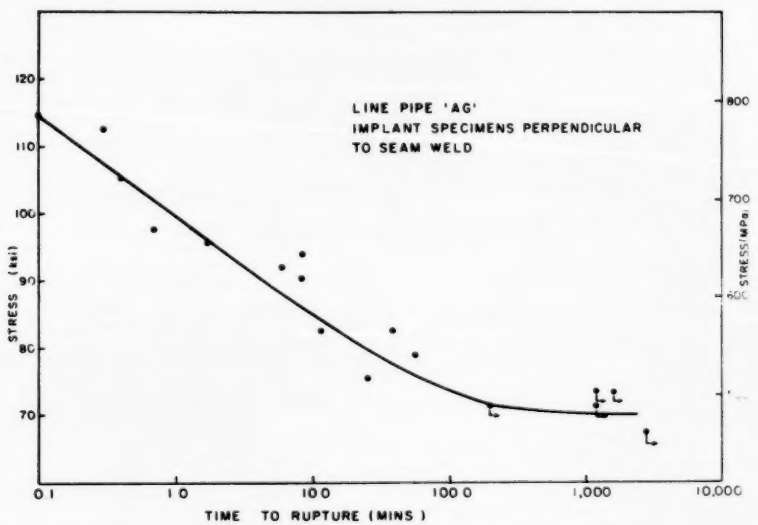


Fig. 6. Implant test results for specimens oriented perpendicular to the seam weld. (neg 5908)

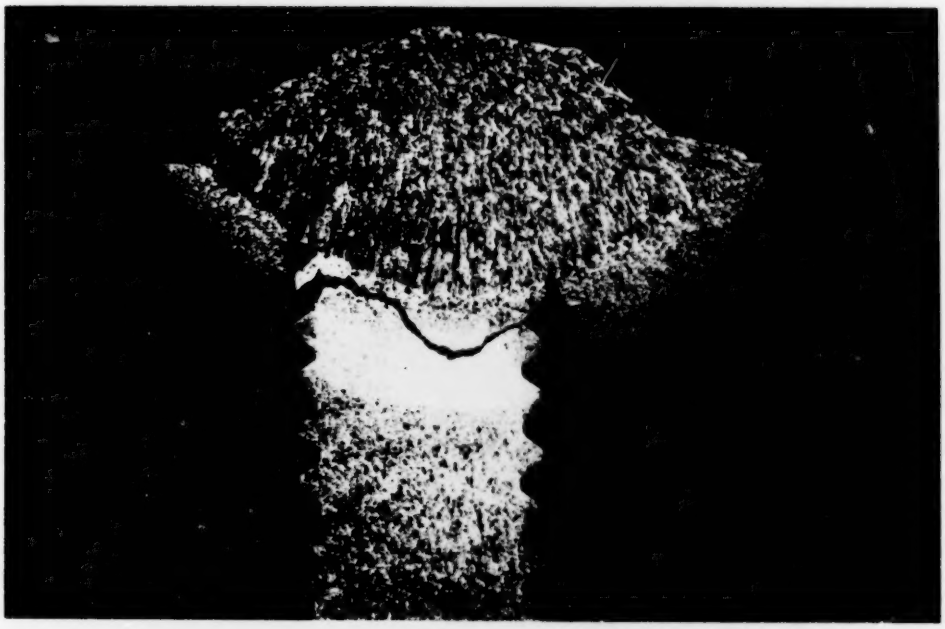


Fig. 7. Cross section through fractured implant specimen oriented perpendicular to the seam weld. X5. (neg 5910)

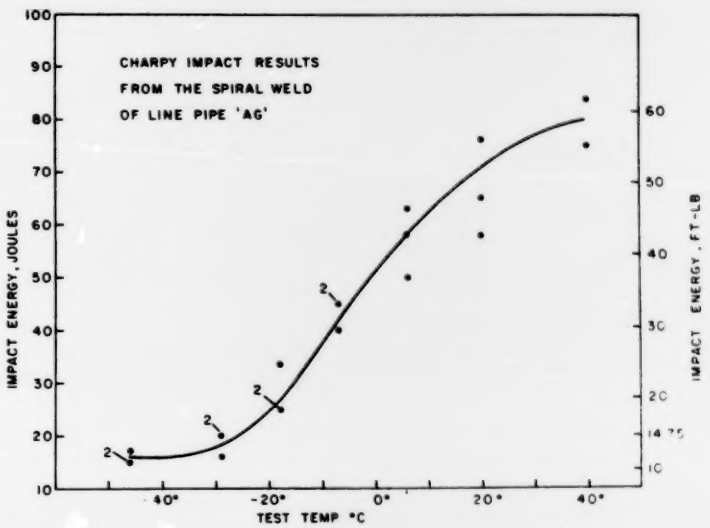


Fig. 8. Charpy impact transition curve of the seam weld metal, with through thickness notch. (neg 5909)

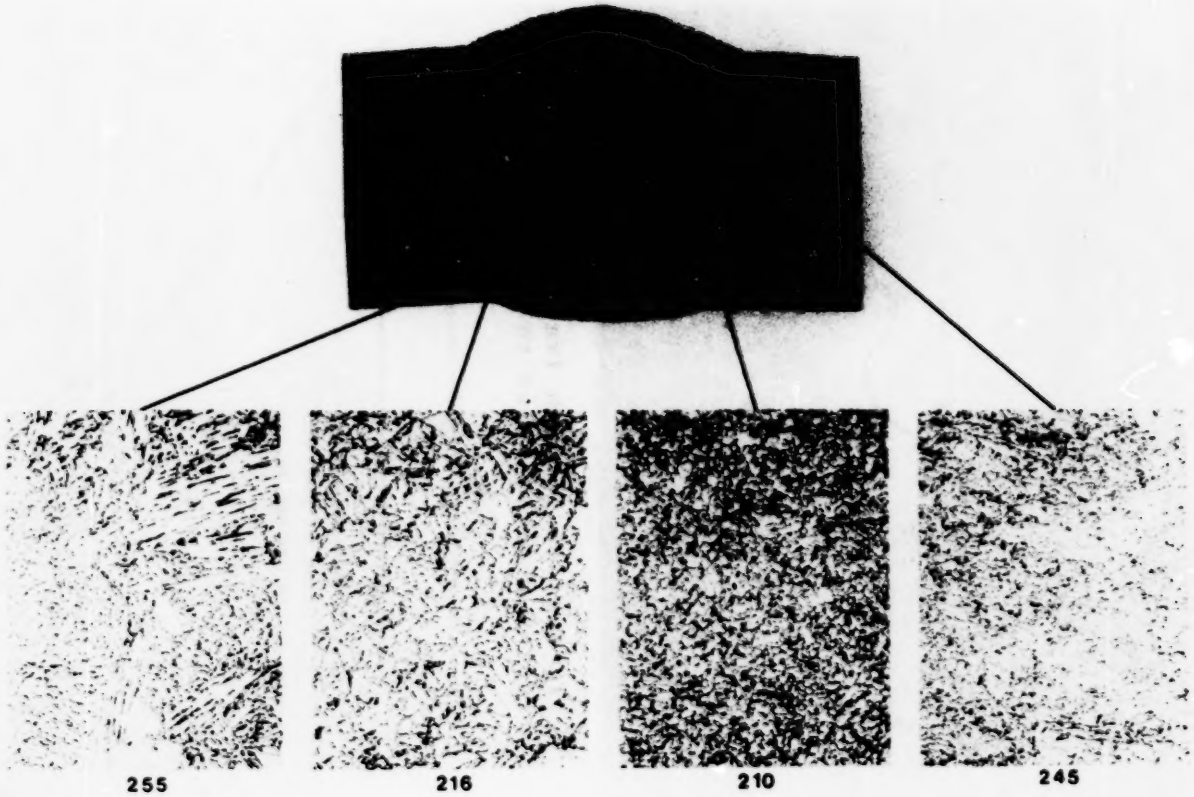
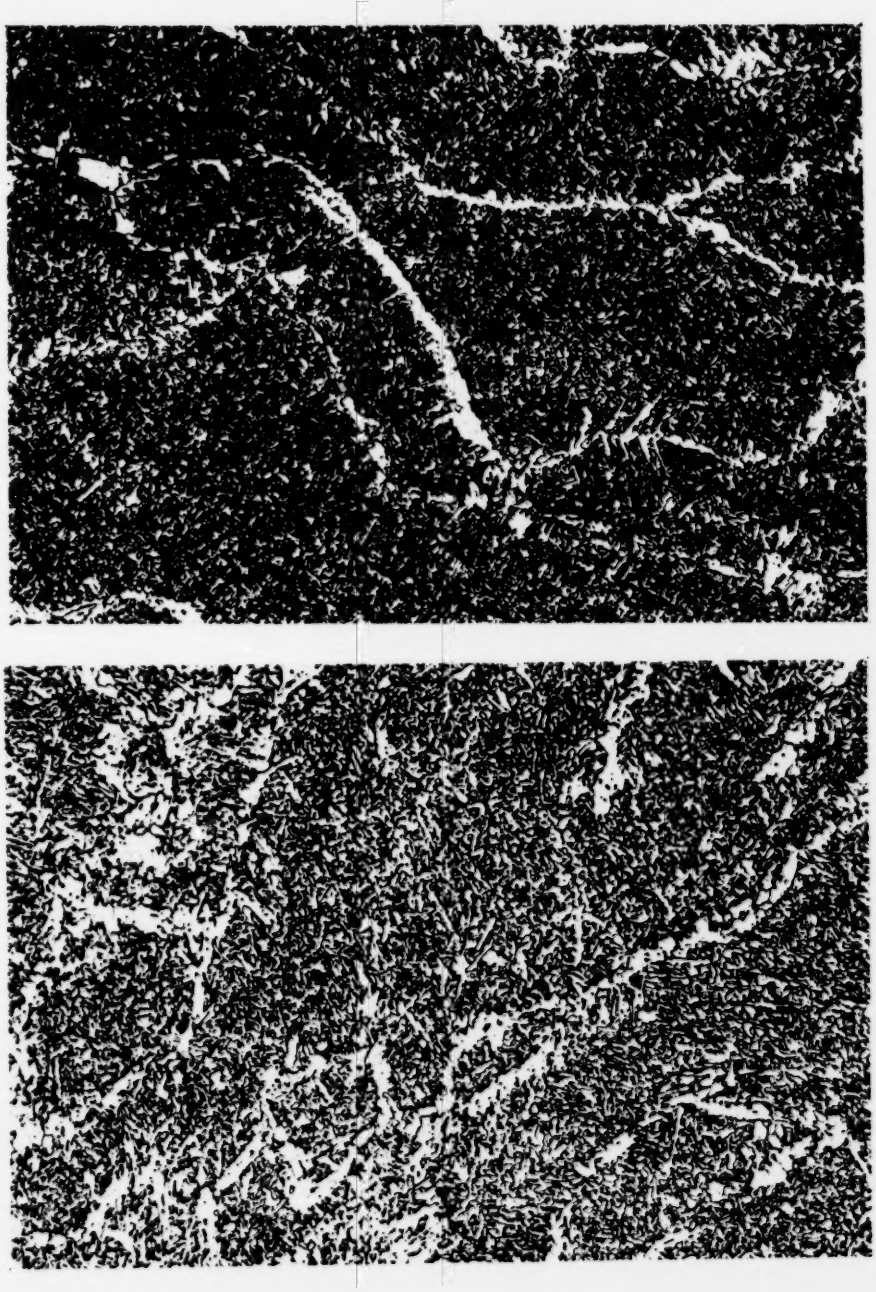


Fig. 9. View of spiral seam-weld and some typical microstructures in the heat-affected zone of pipe "AG". Weld (top) X1.5, microstructures X200 (reduced 3.5 times on reproduction). (a) coarse grained, (b) intermediate, (c) fine-grained and (d) base metal. (neg 5904).



"AB"

"AG"

Fig. 10. Microstructure of the seam weld-metal of pipe "AG" compared with pipe "AB". X250. (negs 6831 and 6832)